

Winter Pea and Lentil Response to Seeding Date and Micro- and Macro-Environments

Chengci Chen,* Perry Miller, Fred Muehlbauer, Karnes Neill, David Wichman, and Kevin McPhee

ABSTRACT

Winter pea (*Pisum sativum* L.) and lentil (*Lens culinaris* Medik.) have potential agronomic advantages over spring types in the Pacific Northwest (PNW) and northern Great Plains (NGP). The objectives of this study were to: (i) determine suitable seeding date and cereal stubble height in no-till systems for winter pea and lentil; (ii) quantify and compare biomass and seed yield of winter pea and lentil with spring types; and (iii) compare adaptation of winter pea and lentil between the PNW and the NGP. Two breeding lines each of winter pea (PS9430706 and PS9530726) and winter lentil [LC9979010 ('Morton') and LC9976079] and two commercial cultivars each of spring pea (CDC Mozart and Delta) and spring lentil (Brewer and CDC Richlea) were sown on different dates (early and late fall dates for winter lines and spring date only for spring cultivars) and into different stubble heights (0.1 and 0.3 m) and compared for yield and agronomic adaptation in no-till systems at four locations: Moccasin and Amsterdam, MT; Genesee, ID; and Rosalia, WA. Stubble height did not influence winter or spring pea biomass production or seed yield. Tall stubble increased lentil biomass by 220 to 530 kg ha⁻¹ and seed yield by 100 to 260 kg ha⁻¹ in five out of nine site-years. Fall-seeded winter pea lines produced as much as 1830 kg ha⁻¹ more seed yield than spring cultivars at the PNW sites, but not at the NGP sites. Early fall-seeded lentil yielded as much as 480 and 590 kg ha⁻¹ greater than spring types in the NGP and PNW, respectively. Delayed fall seeding and reduced stubble height decreased yields more frequently in the NGP than in the PNW.

GROWING pea and lentil provides many benefits to cereal-based cropping systems in the semiarid PNW and NGP. First, the legume crop biologically fixes atmospheric N₂ through symbiosis with *Rhizobium* bacteria making it available to both the legume crop and a subsequent nonlegume crop, thus reducing the need for inorganic N fertilizer inputs (Badaruddin and Meyer, 1994; Beckie and Brandt, 1997; Beckie et al., 1997; Walley et al., 2005). Second, rotating legumes with cereals interrupts disease and pest cycles established in continuous cereal crops (Stevenson and van Kessel, 1996; Derksen et al., 2002; Krupinsky et al., 2002). Third, pea and lentil conserve soil water for the subsequent cereal crops because of their shallow rooting depth (Nielsen, 2001; Miller et al., 2002, 2003; Miller and Holmes, 2005). Finally, introducing pea and lentil to cereal-based cropping systems provides commodity and economic diversity (Zentner et al., 2002). Nevertheless, crop production is often limited by terminal drought (plants suffer lack of water

during the late stages of reproductive growth) and heat stress in the semiarid PNW and NGP. Early seeding has been promoted to avoid terminal drought and improve crop yields (Johnston et al., 1999; Gan et al., 2002; Chen et al., 2003, 2005), but cool and wet soil conditions in the early spring, or general time constraints resulting from a high volume of spring field work often prevent early sowing.

Winter pea and lentil have a longer growing period with earlier spring growth and flower initiation that enables them to avoid terminal heat and water stress in midsummer compared with spring pea and lentil. However, yield advantages of winter pea and lentil over spring types have not been well documented in the semiarid PNW and NGP. Winter pea has been tested for potential use as a winter cover crop (Holderbaum et al., 1990), forage (Murray et al., 1985), and green manure (Auld et al., 1982; Mahler and Auld, 1989). In previous studies, winter pea was planted in pure stands or in mixtures with a cereal for forage (Murray et al., 1985; Hofstetter, 1994; Chen et al., 2004). Interest in growing winter pulse crops has recently increased with the release of winter legume cultivars that have greater yield potentials and have had seed coat pigmentation in the pea removed (Suszkiw, 2005; F. Muehlbauer and K. McPhee, personal communication, 2006).

Benefits from growing dry pea and lentil in cereal stubble of no-till cropping systems have been widely reported. Benefits include reduced soil erosion (Papendick and Miller, 1977), increased snow trapping that improves moisture conservation, reduced wind speeds that lessen evaporative demand for water, and altered microclimate for improved water use efficiency during the growing season (Cutforth et al., 2002). Huggins and Pan (1991) compared two no-till stubble heights (0.35 and 0.05 m) to conventionally tilled treatments for their effects on winter pea and lentil growth and yield in northern Idaho. They found that both stubble heights enhanced soil moisture conservation and increased early growth of Austrian winter pea compared with conventional tillage. Average grain yield was greater in the 0.35 m (3570 kg ha⁻¹) and 0.05 m (3530 kg ha⁻¹) stubble than in conventional tillage (2700 kg ha⁻¹). Tall stubble limited sunlight penetration, thereby affecting the morphology and biomass production of the winter legumes. Winter pea and lentil grown under tall stubble had longer internodes and greater overall vine length. Further studies are needed to determine suitable residue management strategies for winter pea and lentil in the contrasting climates of the PNW and NGP.

Fall seeding may not occur until timely rainfall wets the seedbed to a depth of 0.1 m or greater. A dry seedbed often results in decreased yields of winter legumes

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Published in Agron. J. 98:1655–1663 (2006).

Legumes

doi:10.2134/agronj2006.0085

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Abbreviations: NGP, northern Great Plains; PNW, Pacific Northwest.

(Murray et al., 1979) or complete lack of crop establishment. Optimum seeding dates for winter pea and lentil have not been well documented in the inland PNW or in the NGP. Although dryland producers have no control over the amount and timing of fall rainfall, it would be valuable to know the crop production risk associated with delayed fall seeding dates. Thus, research is needed to determine the planting window and the impact of delaying seeding dates on plant growth and yield. Murray et al. (1984) reported that seedling vigor and seed yield of Austrian winter pea decreased with delayed seeding from September to October at one of two sites in Idaho.

The PNW and the NGP are separated by the Rocky Mountain Range resulting in sharply contrasting climatic conditions. The PNW is characterized by a Mediterranean type climate with a cool, wet winter and hot, dry summer. The majority of the precipitation is received in the winter and spring and little rain falls from June to August (Chen et al., 2003; Payne et al., 2001). The NGP is characterized by a continental climate with a long and cold winter, a short and warm summer, with large diurnal ranges in temperature, frequent strong winds, and uncertain and highly variable summer precipitation (Padbury et al., 2002).

The objectives of this study were to: (i) determine optimal seeding dates and cereal stubble height for optimal winter legume survival and yield under no-till practices; (ii) quantify and compare biomass and seed yield of winter pea and lentil with spring types; and (iii) compare the adaptation of winter pea and lentil between the semiarid inland PNW region and the eastern Rocky Mountain front region of the NGP.

MATERIALS AND METHODS

A 3-yr study was conducted at Moccasin, MT (47°03'3" N, 109°57'3" W, 1400 m elevation) and Amsterdam, MT

(45°44'45" N, 111°26'30" W, 1490 m elevation), and a 2-yr study at Genesee, ID (46°33'03" N, 116°55'28" W, 815 m elevation), and Rosalia, WA (47°16'29" N, 117°17'1" W, 680 m elevation) (Fig. 1). Soils at Moccasin are classified as fine-loamy, carbonatic Typic Calciborolls (Judith clay loam series) and soils at Amsterdam are classified as fine-silty, mixed Typic Haploborolls (Amsterdam silt loam series). Soils at Genesee and Rosalia are classified as fine-loamy, mixed, mesic Pachic Ultic Haploxerolls (Palouse series). Long-term average monthly air temperature and precipitation are presented in Fig. 2 for each location. The typical frost-free period is 110 d at Moccasin, 98 d at Amsterdam, and 130 d at Genesee and Rosalia, respectively. Table 1 displays the monthly precipitation for each location during the experimental period.

Two elite breeding lines of winter pea (PS9430706 and PS9530726) and winter lentil (LC9979010 and LC9976079) from the USDA-ARS, Grain Legume Genetics and Physiology Research Unit in Pullman, WA, were used for this study. Line LC9979010 was subsequently released as the cultivar Morton. Two commonly grown commercial cultivars of spring pea (CDC Mozart and Delta) and spring lentil cultivars (Brewer and CDC Richlea) were also used for this study. Line PS9430706 (706) is a long-vined, yellow pea with semileafless (afila) morphology while line PS9530726 (726) is a semidwarf, semileafless, green pea. Both lines have a clear seed coat without pigmentation and small seed size (140 mg seed⁻¹). CDC Mozart (Mozart) and Delta are semidwarf, semileafless, yellow field pea cultivars, with a medium seed size (200 mg seed⁻¹). Morton and LC9976079 (079) are both Turkish red-type lentil lines with red cotyledons and both have small seed size (35 mg seed⁻¹). Brewer and CDC Richlea (Richlea) have a green seed coat (slight pigmentation in Brewer) and yellow cotyledon with medium seed size (55 mg seed⁻¹).

Winter and spring pea and lentil lines and cultivars were sown directly into cereal stubble cut to heights of 0.3 and 0.1 m representing tall and short stubble heights, respectively. Stubble blocks were bordered on all sides by a minimum 3.6-m-wide strip of the same stubble height to minimize edge effects. Winter pea and lentil were planted at two fall seeding dates (early and late) ranging between 12 September and 2 November, while spring pea and lentil were planted at one spring date

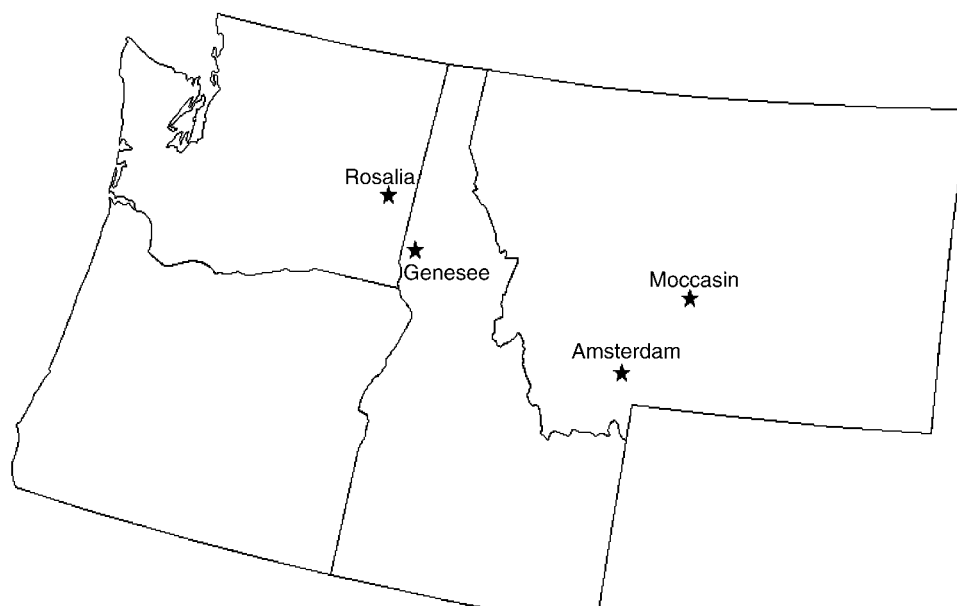


Fig. 1. Experimental sites at Moccasin, MT, and Amsterdam, MT (the northern Great Plains sites), and Genesee, ID, and Rosalia, WA (the Pacific Northwest sites).

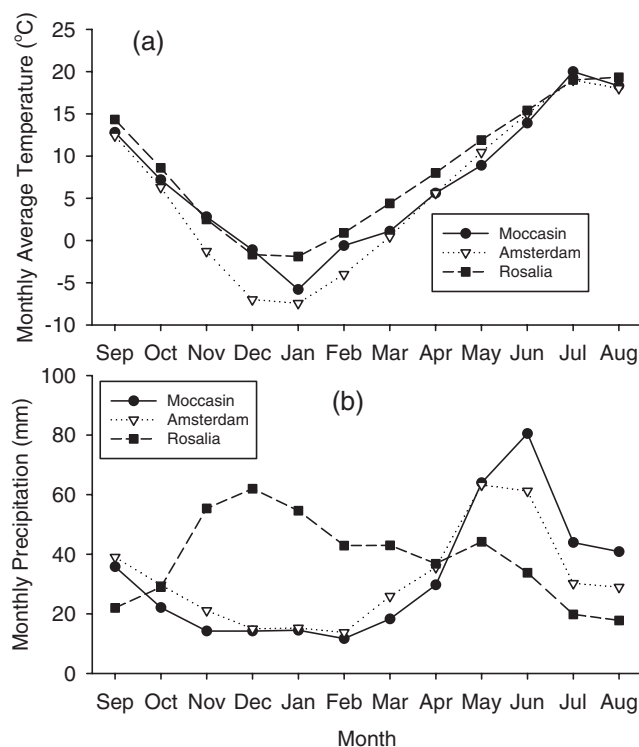


Fig. 2. Long-term (93 yr for Moccasin, 64 yr for Amsterdam, and 57 yr for Rosalia) monthly average: (a) temperature, and (b) precipitation for the three experimental sites.

ranging between 8 April and 6 May (Table 2). Since spring pea and lentil were not planted in the fall in this study, and vice versa, seeding date and cultivar combinations were defined as planting treatments.

The experiment was designed as a split-plot factorial with four replications. The cereal [wheat (*Triticum aestivum* L.) or barley (*Hordeum vulgare* L.)] stubble height treatments were assigned to main plots and planting treatments were randomly assigned to subplots within main plots. Plot size varied slightly among locations, ranging from 1.5 to 1.8 m in width to 12.2 to 14.0 m in length. Pea and lentil were seeded at rates of 86 and 118 seeds m^{-2} , respectively, using no-till plot drills at 0.26- to 0.30-m row spacing. Seed was inoculated with commercial *Rhizobium* inoculants at Amsterdam and Moccasin. Fertilizer N-P-K-S was applied at seeding at rates of 0–7–8–12 and 15–7–21–9 $kg\ ha^{-1}$ at Amsterdam in 2002 and 2003, respectively, and

no fertilizer was applied at the other sites. Roundup [glyphosate, *N*-(phosphonomethyl) glycine, in the form of its isopropylamine salt] was applied as preplant weed control and Assure II [quizalofop p-ethyl, Ethyl(*R*)-2-[4-(6-chloroquinoloxalin-2-yloxy)-phenoxy] propionate] was applied at recommended rates for postemergence grass species weed control. At Amsterdam, in addition to Roundup and Assure II, Sonalan 10G [ethalfluralin, *N*-ethyl-*N*-(2-methyl-2-propenyl)-2,6-dinitro-4-(trifluoromethyl)benzenamine] was applied at 12.2 $kg\ ha^{-1}$ on 22 Oct. 2001, and Sencor DF [metribuzin, 4-amino-6-(1,1-dimethylethyl)-3-(methylthio)-1,2,4-triazin-5(4H)-one] was applied at 150 $g\ ha^{-1}$ on 8 Apr. and 15 May 2002. Broadleaf weed control at the Genesee and Rosalia locations was accomplished through application of 141 $g\ ha^{-1}$ of Pursuit [imazethapyr, (+)-2-[4,5-dihydro-4-methyl-4-(1-methylethyl)-5-oxo-1*H*-imidazol-2-yl]-5-ethyl-pyridoxine carboxylic acid] and grass species weeds were controlled with an application of Assure II.

At plant maturity, total aboveground plant biomass was hand harvested from five 1-m long rows in each plot and weighed. Grain was threshed from each sample and weighed. The remainder of the plot was harvested with a plot combine. Plot grain yield was calculated as the combine plus hand harvest sample weights.

Analysis of variance (ANOVA) was performed separately for pea and lentil for biomass and seed yield data to determine the effects of stubble height and planting treatments. A model for a split-plot design was used with data pooled over four locations and 2 yr (2002 and 2003). Year was considered a random effect and location was considered a fixed effect (McIntosh, 1983). Significant interactions between planting treatment and location and year were detected, therefore, separate ANOVAs were performed for each site-year. Main treatment means were compared according to a protected LSD at $P = 0.05$ and no stubble \times planting treatment interaction was detected.

RESULTS

Annual precipitation varied by year and location (Table 1). The greatest amount received each year was at Genesee. More importantly, precipitation pattern varied between the PNW and NGP sites. During four site-years, Genesee and Rosalia received 77 to 88% of their annual precipitation from September to April, averaging only 14% of their annual total during the May–July growing season. In contrast, during five site-years, Moccasin and Amsterdam received 25 to 61% of their annual precipitation from September to April, and

Table 1. Monthly and annual precipitation received during the study period and long-term average (LTA) at Moccasin, MT, Amsterdam, MT, Genesee, ID, and Rosalia, WA.

Month	Moccasin				Amsterdam			Genesee			Rosalia		
	2001–2002	2002–2003	2003–2004	LTA	2001–2002	2002–2003	LTA	2001–2002	2002–2003	LTA	2001–2002	2002–2003	LTA
Sept.	47	41	33	36	38	32	39	6	10	NA†	7	9	22
Oct.	11	16	25	22	8	9	30	60	11	NA	52	3	29
Nov.	2	2	6	14	5	13	21	47	138	NA	69	30	55
Dec.	1	8	43	14	0	2	15	36	21	NA	67	60	62
Jan.	14	16	15	15	16	35	15	34	74	NA	41	85	55
Feb.	6	11	12	12	8	16	14	26	62	NA	24	29	43
Mar.	11	14	14	18	11	24	26	86	48	NA	19	84	43
Apr.	8	93	24	30	19	85	36	33	39	NA	13	45	37
May	41	57	64	64	84	52	63	16	26	NA	27	39	44
June	73	47	51	81	86	61	61	38	9	NA	23	3	34
July	68	10	25	44	38	14	30	9	8	NA	11	1	20
Aug.	117	14	29	41	26	16	29	35	10	NA	3	14	18
Total	400	329	342	391	339	359	379	425	456	NA	356	402	462

† NA represents data not available.

Table 2. Fall and spring planting dates at Moccasin, MT, Amsterdam, MT, Genesee, ID, and Rosalia, WA, from 2002 to 2004.

Planting	2001–2002				2002–2003				2003–2004
	Moccasin	Amsterdam	Genesee	Rosalia	Moccasin	Amsterdam	Genesee	Rosalia	Moccasin
Early	18 Sept. 2001	12 Sept. 2001	15 Oct. 2001	5 Oct. 2001	16 Sept. 2002	13 Sept. 2002	9 Oct. 2002	9 Oct. 2002	12 Sept. 2003
Late	2 Oct. 2001	26 Sept. 2001	2 Nov. 2001	29 Oct. 2001	30 Sept. 2002	30 Sept. 2002	28 Oct. 2002	30 Oct. 2002	30 Sept. 2003
Spring	17 Apr. 2002	11 Apr. 2002	12 Apr. 2002	12 Apr. 2002	11 Apr. 2003	9 Apr. 2003	6 May 2003	6 May 2003	8 Apr. 2004

averaged 44% of annual precipitation during the critical May–July growing season. Summer drought characterized all sites and affected final grain yield.

The ANOVA results for pea and lentil (Table 3) revealed that there were significant effects of year, and year \times site interactions for biomass and seed yield. Stubble height did not influence biomass and seed yield of pea (Table 3). However, a stubble height \times year interaction occurred for lentil seed yield, indicating the stubble height effects on lentil differed among years. Planting treatment interactions with sites and years were detected for both crops (Table 3), therefore, separate ANOVAs were performed for each site-year.

Moccasin, MT

In general, pea biomass did not differ between the winter pea lines (706 and 726) sown early in the fall or between the spring cultivars (Mozart and Delta) in 2002 and 2003 (Fig. 3a). The early, fall sown winter pea lines had an average of 1750 kg ha⁻¹ greater biomass yield than spring cultivars in 2004 (Fig. 3a). Delayed fall seeding decreased biomass of winter pea lines in 2004, but had no effect in 2002 and 2003.

Lower seed yields in 2003 compared with 2002 and 2004 reflected the most severe drought of the 3 yr in this study (Fig. 3b). The early seeded winter pea line 726 yielded similarly to the spring cultivars in 2002 and 2004, and yielded similar to Mozart, but less than Delta in 2003 (Fig. 3b). Line 706 did not yield as well as the spring cultivars in most cases, even when planted early in the fall (Fig. 3b). In 2002 and 2004, line 726 had greater seed

yield than line 706 at the early seeding date, but not at the late seeding date.

Early planted winter lentil had greater biomass than spring lentil in all 3 yr (Fig. 4a). Similar to winter pea, delayed fall seeding of winter lentil reduced biomass accumulation in 2004. There was no difference in biomass accumulation between Morton and line 079 winter lentil.

Morton winter lentil planted early in the fall had greater seed yield than Brewer all 3 yr and produced better than Richlea 2 of 3 yr (Fig. 4b). The early seeded winter lentil line 079 yielded greater than Brewer spring lentil in 2002 and 2003, but had similar yield in 2004. Delayed fall seeding decreased seed yield of winter lentil in 2 of 3 yr. In 2003, a year with severe summer drought, early seeded winter lentil cultivars yielded an average of 470 kg ha⁻¹ greater than spring lentil cultivars. Yields did not differ between Morton and line 079 when seeded early in the fall. Lentil seed yield was consistently greater in tall stubble compared with short stubble at Moccasin by an average of 180 kg ha⁻¹ (data not shown).

Amsterdam, MT

Establishment of winter pea and lentil at the 2004 Amsterdam site failed completely due to persistent dry fall seedbed conditions; consequently the site was abandoned. Winter pea line 706 seeded early in the fall had similar biomass compared with the spring pea cultivars (Fig. 5a). However, early seeded line 726 had less biomass than Delta spring pea in both years and less than Mozart spring pea in 2002. Early seeded winter pea lines

Table 3. Sum of squares and significant levels from analysis of variance for pea and lentil biomass and seed yield pooled over four locations (Moccasin, Amsterdam, Genesee, and Rosalia) and 2 yr from 2002 to 2003.

Source	df	Pea		Lentil	
		Biomass	Seed yield	Biomass	Seed yield
Year	1	1.52E + 08**	5.14E + 07**	7.44E + 06**	2.70E + 04
Site	3	2.55E + 08	5.31E + 07	1.33E + 08*	5.23E + 05
Year \times site	3	1.98E + 08**	3.96E + 07**	9.40E + 06*	4.81E + 06**
Block/year \times site	24	8.34E + 07	1.68E + 07	1.61E + 07	2.62E + 06
Stubble	1	2.73E + 05	4.96E + 04	1.48E + 06	2.65E + 05
Stubble \times year	1	1.86E + 04	3.19E + 05	8.17E + 05	6.57E + 05**
Stubble \times site	3	8.29E + 05	1.16E + 06	5.05E + 06	6.05E + 05
Stubble \times year \times site	3	4.18E + 06	3.65E + 05	2.99E + 06	5.92E + 05
Whole plot error	24	1.92E + 07	3.48E + 06	1.13E + 07	1.91E + 06
Planting	5	2.01E + 08	7.20E + 06	1.76E + 07	4.56E + 06
Planting \times year	5	5.91E + 07**	6.15E + 06**	5.59E + 06*	1.87E + 06**
Planting \times site	15	3.18E + 08	4.97E + 07*	7.70E + 07*	1.33E + 07*
Planting \times year \times site	15	1.38E + 08**	1.58E + 07**	3.04E + 07**	4.37E + 06**
Planting \times stubble	5	1.87E + 06	1.47E + 05	1.05E + 06	8.78E + 04
Planting \times stubble \times year	5	4.39E + 06	1.11E + 05	5.59E + 05	1.18E + 05
Planting \times stubble \times site	15	1.82E + 07	7.33E + 05	5.55E + 06*	3.74E + 05
Planting \times stubble \times year \times site	15	1.09E + 07	5.41E + 05	1.65E + 06	2.65E + 05
Subplot error	240	1.79E + 08	1.15E + 07	5.41E + 07	4.88E + 06

* Significant at $P < 0.05$.

** Significant at $P < 0.01$.

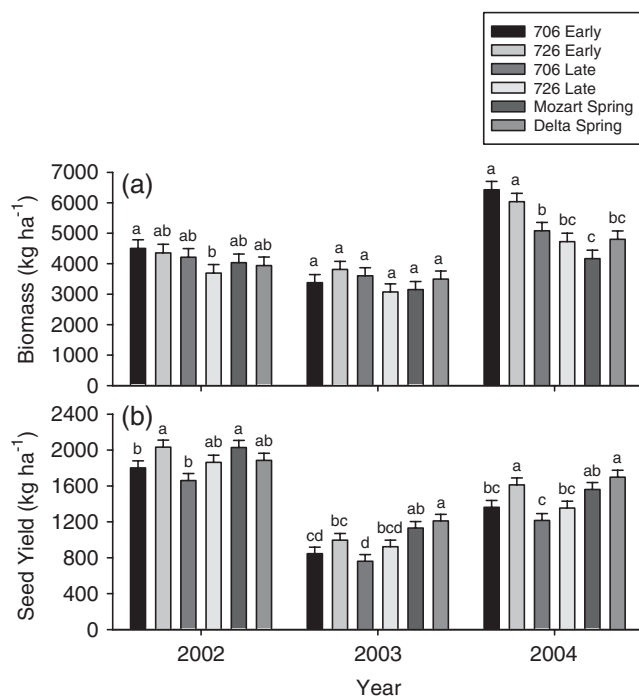


Fig. 3. Biomass and seed yield of winter and spring pea planted at early and late-fall and spring seeding dates at Moccasin, MT, in 2002, 2003, and 2004. Different letters atop each bar indicate a significant difference according to Fisher's protected LSD ($P = 0.05$). Error bars represent ± 1 SE.

706 and 726 did not differ in biomass in 2002. But line 706 produced greater biomass than 726 in 2003. Delayed fall seeding for winter pea line 706 resulted in decreased

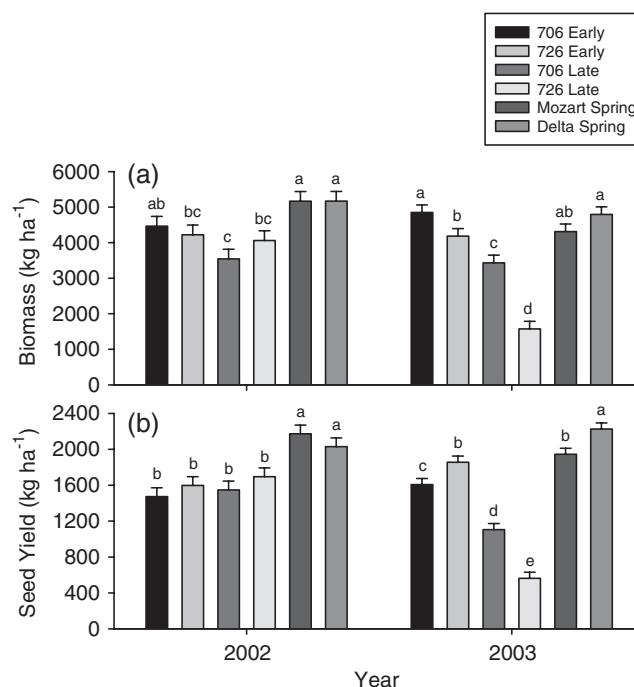


Fig. 5. Biomass and seed yield of winter and spring pea planted at early and late-fall and spring seeding dates at Amsterdam, MT, in 2002 and 2003. Different letters atop each bar indicate a significant difference according to Fisher's protected LSD ($P = 0.05$). Error bars represent ± 1 SE.

biomass both years but line 726 only lost yield when planted later during 2003.

Delta spring pea produced greater seed yields than both winter cultivars during 2002 and 2003 (Fig. 5b). Mozart spring pea had similar yield to early planted winter line 726 in 2003, but it yielded greater than both winter cultivars in 2002. Seed yield did not differ between the winter pea lines in 2002, but in 2003 line 726 had better yield than line 706 at the early fall seeding date, while the opposite occurred at the late fall seeding date. Delayed seeding did not affect seed yield for winter pea in 2002. However, winter pea yield decreased in 2003 with the late fall planting.

Richlea spring lentil cultivar produced more biomass than either winter lentil line at both early and late seeding dates in 2002 (Fig. 6a). In 2003, however, both early seeded winter lentil lines produced biomass comparable with the spring cultivars. In 2002, Morton biomass yield was greater than line 079 at late seeding date but less than line 079 at early seeding date. However, they both lost biomass yield in 2003 when planting date was delayed. Similar to biomass, Richlea spring lentil had greater seed yield than winter lentil lines at either early or late seeding date in 2002, but seed yield did not differ between the early seeded winter lentil and spring lentil in 2003 (Fig. 6b). Delayed fall seeding during 2002 had no effect on seed yield, but during 2003 it resulted in an average of 950 kg ha^{-1} less yield. There was no difference in seed yield between Morton and line 079 at either planting date during both years.

Stubble height had inconsistent effects on lentil seed yield. Seed yield in tall stubble was 180 kg ha^{-1} greater

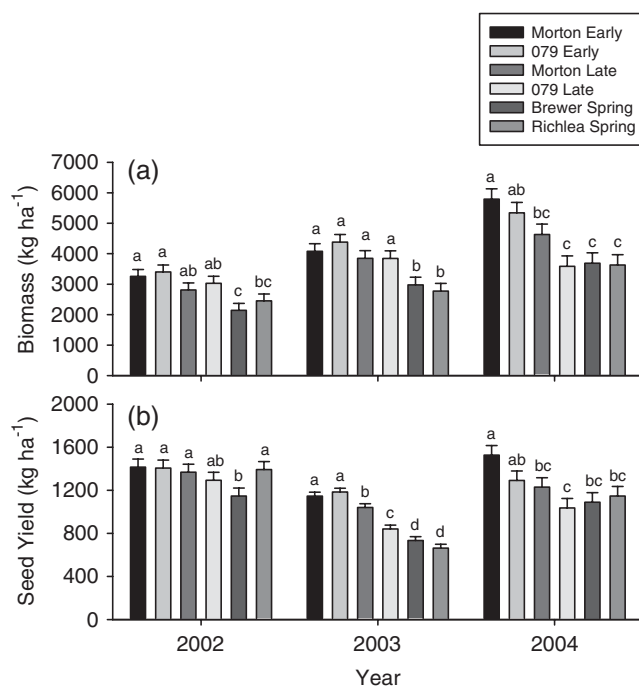


Fig. 4. Biomass and seed yield of winter and spring lentil planted at early and late-fall and spring seeding dates at Moccasin, MT, in 2002, 2003, and 2004. Different letters atop each bar indicate a significant difference according to Fisher's protected LSD ($P = 0.05$). Error bars represent ± 1 SE.

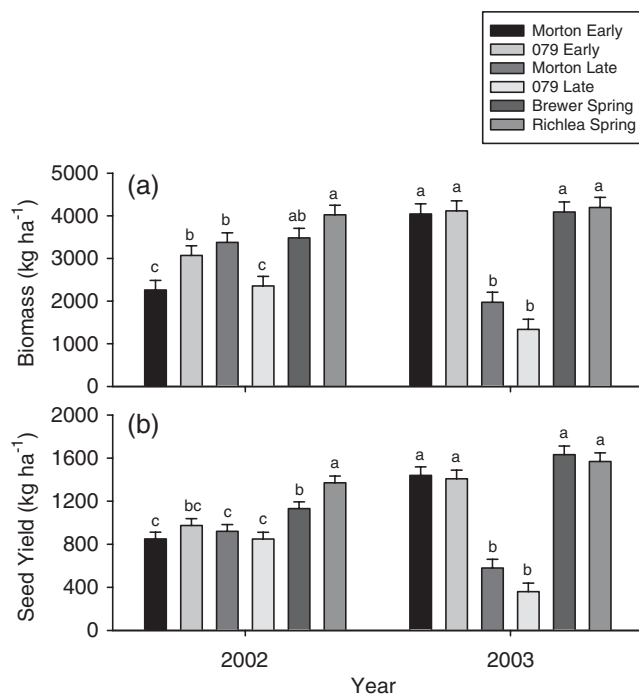


Fig. 6. Biomass and seed yield of winter and spring lentil planted at early and late-fall and spring seeding dates at Amsterdam, MT, in 2002 and 2003. Different letters atop each bar indicate a significant difference according to Fisher's protected LSD ($P = 0.05$). Error bars represent ± 1 SE.

than the short stubble treatment in 2002, but the reverse occurred in 2003 with the short stubble yielding 250 kg ha⁻¹ greater than the tall stubble treatment (data not shown). In 2001, timely fall rain (~10 mm during 5–8 Sept.) permitted excellent germination and seedling establishment for the 2002 winter lentil crop. It is believed that the wetter, cooler microclimate found in the tall stubble reduced the risk of seedling mortality during the subsequent warm, dry fall. In contrast, the fall of 2002 had unusually low degree day accumulation in October, followed by an unusually cool period in March and early April 2003. Crops grown in this heat-limited environment may have benefited from the earlier soil warming associated with the short stubble in the early spring.

Genesee, ID

In 2002, early planted winter pea lines produced greater biomass than the spring cultivars, and the late planted line 706 produced more biomass than the two spring cultivars (Fig. 7a). During 2003, early planting was not successful. Only the late-seeded winter pea line 706 had greater biomass than the spring cultivars. Line 706 produced 4420 (late seeding) to 4830 kg ha⁻¹ (early seeding) and 2240 (early seeding) to 3130 kg ha⁻¹ (late seeding) more biomass than line 726 in 2002 and 2003, respectively. Delayed fall seeding did not affect biomass for either winter pea line during 2002. However, during 2003 biomass production increased for both winter pea lines for the delayed fall seeding date.

Early and late seeded winter pea line 706 had greater seed yield than the spring cultivars in 2002 and 2003.

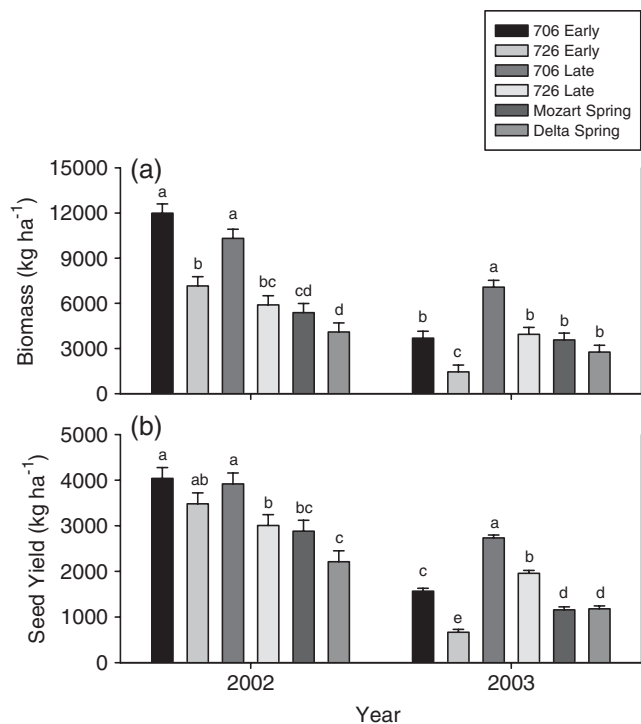


Fig. 7. Biomass and seed yield of winter and spring pea planted at early and late-fall and spring seeding dates at Genesee, ID, in 2002 and 2003. Different letters atop each bar indicate a significant difference according to Fisher's protected LSD ($P = 0.05$). Error bars represent ± 1 SE.

Delayed fall seeding dates did not reduce winter pea yield in 2002, and increased yields in 2003 for both lines (Fig. 7b).

Biomass was consistently greater for the early seeded winter lentil cultivars compared with spring lentil cultivars by an average of 890 kg ha⁻¹ and 650 kg ha⁻¹ in 2002 and 2003, respectively (Fig. 8a). Early seeded Morton winter lentil produced more biomass than line 079 in 2002 and was similar to 079 in 2003. Delayed fall seeding decreased biomass in 2002, but had no effect on biomass yield in 2003. The tall stubble treatment had 220 kg ha⁻¹ more biomass than the short stubble treatment in 2002, but there was no difference between the two stubble treatments in 2003 (data not shown).

Seed yield of early seeded Morton and line 079 winter lentil was 460 and 320 kg ha⁻¹ greater than spring cultivars in 2002, and 590 and 420 kg ha⁻¹ greater than spring cultivars in 2003 (Fig. 8b). Morton winter lentil had greater seed yield than line 079 in 2002. Delayed fall seeding reduced seed yield in all cases. Lentil seed yield was 100 kg ha⁻¹ greater in the tall stubble treatment compared with the short stubble treatment in 2002, but there was no stubble treatment effect in 2003 (data not shown).

Rosalia, WA

All winter pea treatments produced more biomass than spring pea in 2002, with the exception that line 726 seeded late (Fig. 9a). During 2003, all winter pea treatments produced more biomass than spring pea. Winter pea line 706 produced 900 (late seeding) to 1742 kg ha⁻¹ (early seeding) greater biomass than line 726 in 2002, and 998

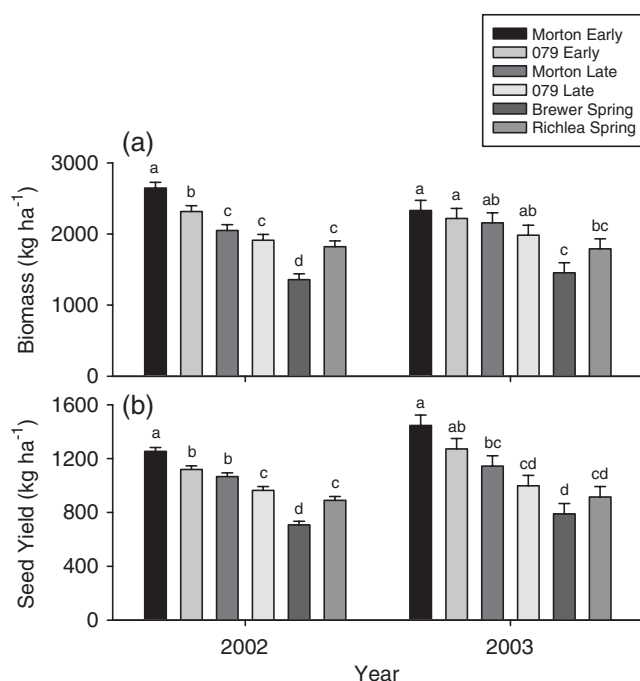


Fig. 8. Biomass and seed yield of winter and spring lentil planted at early and late-fall and spring seeding dates at Genesee, ID, in 2002 and 2003. Different letters atop each bar indicate a significant difference according to Fisher's protected LSD ($P = 0.05$). Error bars represent ± 1 SE.

(early seeding) to 1202 kg ha⁻¹ (late seeding) greater biomass than line 726 in 2003. Biomass production was less for the late fall seeding date in 2002, but not in 2003.

During 2002, the early seeded lines 706 and 726 had 1490 kg ha⁻¹ and 930 kg ha⁻¹ greater seed yield, respec-

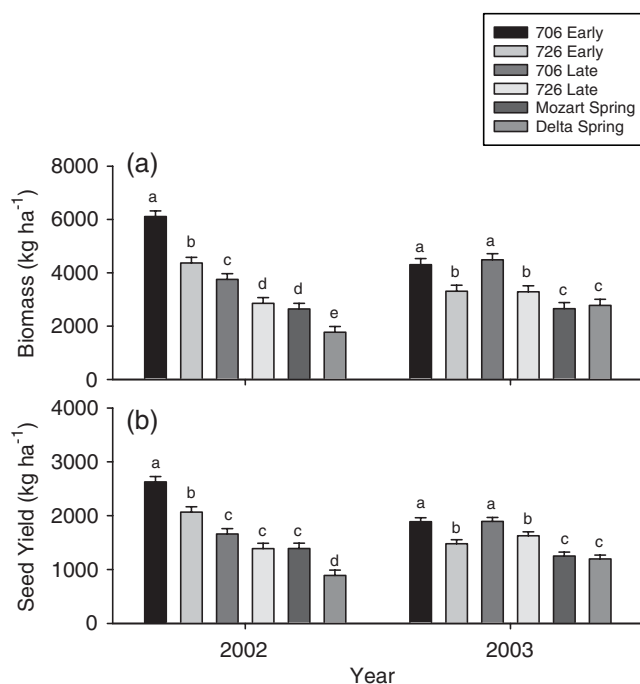


Fig. 9. Biomass and seed yield of winter and spring pea planted at early and late-fall and spring seeding dates at Rosalia, WA, in 2002 and 2003. Different letters atop each bar indicate a significant difference according to Fisher's protected LSD ($P = 0.05$). Error bars represent ± 1 SE.

tively, than spring cultivars. Both early and late-seeded winter pea lines produced greater seed yields than spring cultivars in 2003. Seed yield was 670 kg ha⁻¹ greater for winter pea line 706, and 330 kg ha⁻¹ greater for winter pea line 726 than spring cultivars in 2003, respectively (Fig. 9b). Line 706 had an average of 560 kg ha⁻¹ and 410 kg ha⁻¹ greater seed yield than line 726 in 2002 and 2003, respectively. Delayed fall seeding decreased winter pea seed yields by 970 and 680 kg ha⁻¹ for line 706 and 726, respectively in 2002, but had no effect in 2003.

Lentil biomass and seed yield were inconsistent at Rosalia (Fig. 10a, 10b). In 2002, there were no differences in biomass among planting treatments with the exception of Richlea (Fig. 10a). Morton accumulated more biomass than line 079 and Brewer, but was similar to Richlea in 2003 (Fig. 10a).

Morton yielded greater than Richlea at both early and late seeding dates, and it yielded greater than Brewer at the late seeding date in 2002. Both early and late-sown Morton lentil had greater seed yields than the spring lentil cultivars in 2003 (Fig. 10b). Line 079 yielded either similar or less than the spring cultivars. Morton yielded 160 and 620 kg ha⁻¹ greater than line 079 in 2002 and 2003, respectively. Delayed fall seeding did not affect winter lentil yield due to simultaneous seedling emergence for both seeding dates caused by the dry fall soil conditions at Rosalia.

DISCUSSION

Winter pea cultivars showed greater yield advantage compared with spring pea cultivars in the PNW than in the NGP macroclimate. Two major climatic factors likely

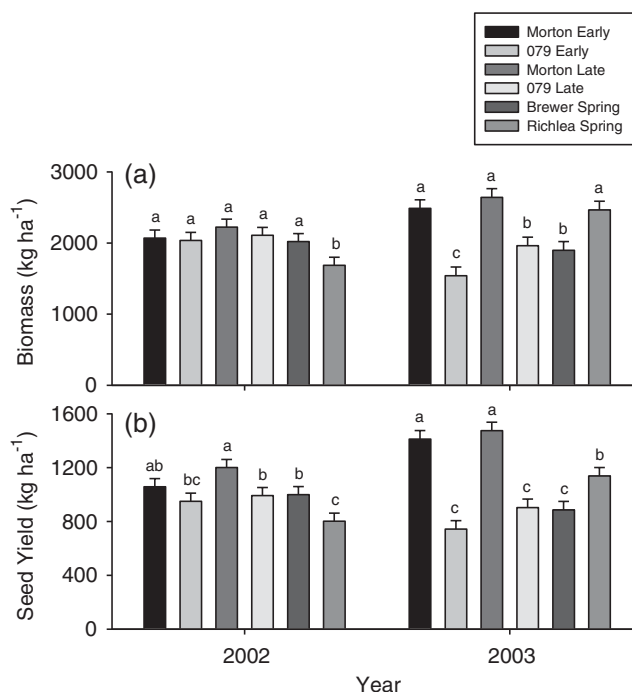


Fig. 10. Biomass and seed yield of winter and spring lentil planted at early and late-fall and spring seeding dates at Rosalia, WA, in 2002 and 2003. Different letters atop each bar indicate a significant difference according to Fisher's protected LSD ($P = 0.05$). Error bars represent ± 1 SE.

contributed to this differential response. First, winter temperatures in the PNW were consistently warmer than the NGP sites (Fig. 2). Average winter temperatures remained near or above freezing in the PNW (Fig. 2) minimizing the extent of tissue necrosis caused by freezing. Frequent below freezing winter temperatures experienced at the NGP locations resulted in severe damage to tissue. Almost all aboveground tissue showed signs of necrosis at Moccasin and Amsterdam, MT. Winter pea and lentil still have difficulty surviving in the highline areas of Montana. Due to the mild winter conditions and extensive growing period in the PNW, winter pea produced up to 7900 kg ha⁻¹ greater biomass and up to 1830 kg ha⁻¹ greater seed yield than spring pea at four PNW site-years (Fig. 7 and 9). However, no yield advantage to winter pea over spring pea was documented at the NGP locations (Fig. 3 and 5). Second, precipitation distribution in the PNW was more favorable for winter pea growth compared with the NGP sites. In the PNW, a typical winter season has well-timed rainy periods that promote growth in winter crops (Table 1, Fig. 2). These cool and wet conditions are ideal for winter pea growth and soil surface evaporation is reduced under these conditions. Conversely, wet spring soil conditions in the PNW typically cause seeding delays for spring pea that strongly limits its yield potential (Gan et al., 2002; Miller et al., 2006). The continental type weather conditions in the Rocky Mountain front area of the NGP are highlighted by precipitation peaks in the summer (Fig. 2). Although timely summer rain can relieve drought conditions in shallow soils, rainfall delivered by summer storms is unreliable and variable resulting in unstable yield over the long term (Fig. 3 and 5). In 2003, for example, only 10 and 14 mm rain were received in July at Moccasin and Amsterdam, respectively. As a result, pea yield was greatly reduced.

The mild winter conditions and longer growing period of the PNW, relative to the NGP locations, favored biomass and seed yield in winter pea at Genesee and Rosalia, especially for line 706 with a long-vined and semileafless (afila) morphology. But line 726, with a semidwarf semileafless morphology, had a greater seed yield compared with line 706 at the Moccasin and Amsterdam sites. This outcome highlighted genotypic differences in adaptation in different environments.

Delayed fall seeding date generally reduced winter pea and lentil biomass and seed yield. Winter lentil was observed to be more sensitive to fall seeding dates than winter pea at Moccasin (Fig. 3 and 4) and Genesee (Fig. 7 and 8). Delayed fall seeding date reduced yield in three of five site-years for winter lentil and two of five site-years for winter pea in the NGP (Fig. 3 through 6), compared with two of four cases for winter lentil and one of four cases for winter pea in the PNW (Fig. 7 through 10). In the PNW, producers have a wider planting window and can plant winter pea and lentil after fall rains moisten the seedbed. In the NGP, however, the fall seeding window is narrow as producers must plant winter pea or lentil by mid-September and then rely on enough moisture in the seedbed to ensure establishment of vigorous seedlings able to survive the winter.

Winter lentil yield was 100 to 260 kg ha⁻¹ greater in the tall cereal stubble treatments than in the short stubble treatments in four of five site-years in the NGP, but in the PNW in the tall stubble treatments lentil yield was 100 kg ha⁻¹ greater than in the short stubble treatments in only one of four site-years (data not shown). This response may be due to increased water use efficiency associated with stubble microclimate as reported previously for spring pea and lentil (Cutforth et al., 2002). Lentil plant height was 4 cm taller in the tall stubble (data not shown), an attribute beneficial for combine harvesting. Huggins and Pan (1991) attributed the stem elongations of pea and lentil under no-tillage to the influence of stubble height on red/far-red ratios. Plants exposed to far-red light have greater stem elongation.

CONCLUSIONS

Different climate patterns in the PNW and NGP resulted in differential adaptation for genotypes of both pea and lentil. With a Mediterranean type climate and mild winter conditions in the PNW, winter pea cultivars demonstrated greater yield potential than spring pea cultivars, and the long-vined winter pea line 706 out-yielded the semidwarf winter pea line 726. In the NGP with a continental climate, cold winter conditions and a short growing season, winter pea cultivars did not demonstrate a yield advantage over spring pea cultivars, and the semidwarf winter pea line 726 out-yielded the long-vined winter pea line 706 for the early fall seeding date. Winter lentil cultivars demonstrated a yield advantage over spring lentil cultivars in both the PNW and NGP, especially in years with summer drought. In the PNW, early fall seeding into tall stubble was not as critical as in the NGP where harsh winter conditions and short growing seasons existed. However, establishment of the winter pulse crops as early in the fall as possible will likely increase the winter survival and productivity of the crops in most environments.

ACKNOWLEDGMENTS

The authors gratefully acknowledge funding support from the USDA Cool Season Food Legume Program and farmer collaboration: Matt Flikkema (Amsterdam, MT), Russ Zenner (Genesee, ID), and Joe Schmitz (Rosalia, WA). Technical expertise was capably provided by Jeff Holmes, Karnes Neill, Rick Short, Chris Hoagland, and Mike Sill.

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